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Quarterly Technical Summary

General Research

15 August 1966

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MASSACHUSETTS INSTITUTE OF TECHNOLOGY

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INTRODUCTION

This Quarterly Technical Summary covers the period from 1 May through 31 July 1966. It consolidates the reports of Division 2 (Data Systems), Division 3 (Radio Physics), Division 4 (Radar), Division 7 (Engineering), and Division 8 (Solid State) on the General Research Program at Lincoln Laboratory.

Accepted for the Air Force
Franklin C. Hudson
Chief, Lincoln Laboratory Office

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DATA SYSTEMS DIVISION 2

INTRODUCTION

This section of the report reviews progress during the period 1 May through 31 July 1966 for the General Research Program of Division 2. Separate progress reports on Ballistic Missile Re-entry Systems, Graphics, and Project PRESS describe other work in the Division. All the work of Groups 21 and 22 and some of the work of Groups 23, 25, and 28 is therefore reported separately.

F. C. Frick
Head, Division 2

V. A. Nedzel
Associate Head



DIVISION 2 REPORTS ON GENERAL RESEARCH

15 May through 15 August 1966

PUBLISHED REPORTS

Journal Articles*

JA No.

2658	Optical Scattering from Cubic Electro-Optical Films	D.O. Smith	Optica Acta <u>13</u> , 121 (1966)
2748	The Effect of Mercury Contamina- tion on the Work Function of Gold	E.E. Huber, Jr.	Appl. Phys. Letters <u>8</u> , 169 (1966)
2751	Trial Spacing in Instrumental Running	J. L. Fozard	Psychol. Reports <u>18</u> , 623 (1966)
MS-1468A	Origin of Quadrature Flux in Magnetic Films	K.J. Harte M.S. Cohen G.P. Weiss D.O. Smith	Phys. Stat. Sol. <u>15</u> , 225 (1966)

* * *

UNPUBLISHED REPORTS

Journal Articles

JA No.

2781	Work Function Changes Due to the Chemisorption of Water and Oxygen on Aluminum	E.E. Huber, Jr. C.T. Kirk	Accepted by Surface Sci.
2783	Operating Characteristics from Yes-No and Forced-Choice Procedures	A.I. Schulman R.R. Mitchell	Accepted by J. Acoust. Soc. Am.

Meeting Speeches†

MS No.

1508	NiFeCu Films	M.S. Cohen	Intermag Conference, Stuttgart, Germany, 20-22 April 1966
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* Reprints available.

† Titles of Meeting Speeches are listed for information only. No copies are available for distribution.

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MS No.

1547	The Effect of Repetition of the Apparent Recency of Pictures	J. L. Fozard D.B. Yntema	Eastern Psychological Association, New York, 14-16 April 1966
1596	Computer Optimization of the Baseband Design of a Unified Carrier Space-Ground Communi- cation Link	H. C. Peterson W. F. Higgins*	National Telemetering Conference, Boston, 10-12 May 1966

* Author not at Lincoln Laboratory.

DIGITAL COMPUTERS GROUP 23

I. COMPUTER SYSTEMS

A. TX-2

The main core memory of TX-2 is now composed of six 16 K modules with a 2 μ sec cycle time. These have been in use for several months with an interim memory bus switch. A new bus switch is now partially installed. When it is completed, any two of the present six modules will be operable at the same time. The new switch also provides for connecting up to eight memory modules and for operating up to four modules concurrently. It will also provide considerably faster memory accessing, both with respect to SPAT* and input/output operations.

The design of the Memory Snatch input/output channels continues to be improved. Large portions of the control circuitry for memory snatch cycles were moved from TX-2 type hardware to SPAT-type hardware where the faster circuit operation gives cleaner and faster execution of the necessary micro-operations during the memory snatch cycle.

This work reflects the developing need for efficient operation of input/output devices in the APEX time-sharing mode. The detection of various alarm and error events by SPAT has also been considerably refined. This effort has been principally aimed at simplifying the debugging of new hardware and software time-sharing system facilities.

B. Micrologic Assemblies

The expanded Miscellaneous Input Sequence has been installed and is in use.

C. TX-2 Optical Scanner

Hardware for DC operation of mercury vapor and fluorescent light sources has been completed and checked out. This concludes the search for a solution to a seemingly trivial problem of illumination for scanned documents and objects. One 400-watt bulb or up to four independent 100-watt mercury lamps may now be used for ripple-free light. All mechanical and electrical modifications to the image dissector camera and driving circuitry have been made and are ready for checkout.

D. Experimental Input Stylus

An experimental input stylus device has been built which utilizes a search coil in a time-varying magnetic field gradient to provide X-Y position information. Operation is relatively independent of stylus inclination, and provides a resolution of approximately 10 mils over a 10-inch area at a sampling rate of 60kc. During the next quarter, the device will be evaluated and improvements made.

* General Research Quarterly Technical Summary Report, Lincoln Laboratory, M.I.T. (15 May 1965), DDC 619676; Quarterly Progress Report, Div. 2, Data Systems, Lincoln Laboratory, M.I.T. (15 February 1965), AD 612541; Quarterly Progress Report, Div. 2, Data Systems, Lincoln Laboratory, M.I.T. (15 February 1964), AD 432493.

II. CIRCUIT DEVELOPMENT

A. High Speed Integrated Circuits

A five-stage ring of Philco experimental ECL circuits, type SMX-2, incorporating 2.5-micron electrode widths, was put into operation with a fanout of one for evaluation purposes. Supply voltages were $V_{CC} = +1.6$ volts, $V_{EE} = -2.0$ volts, $V_{REF} = 0$ volts. The delay per stage was measured as 455 picoseconds.

B. Microsystems

All the masks have been completed for the integrated parity system being fabricated at Philco Lansdale. The basic cell is 17×15 mils and contains 40 transistors and 18 resistors. This will produce a 3-input parity. Initial tests will be made on the basic cell. Thirteen of the basic cells will be interconnected with two levels of metallization to form a 27-bit parity system which is expected to generate a parity output in less than 2 nanoseconds.

C. Integrated Circuit Tester

A Fairchild integrated circuit handler has been modified and incorporated in the DC Tester. The handler now accepts custom-made cartridges loaded with 50 integrated circuits in Fairchild carriers. Carriers are gravity fed down an incline to the test head and accepted units are received by an empty cartridge below. A chute drops failures into a box under the handler.

D. New TX-2 Packages

The manually operated tester (T-3) is being modified to provide more versatility. A flip flop (TX-2) and three inverter test units have been constructed. The inverter test units are for the new version of inverter packages proposed for use in TX-2. These packages have been designated P6-1, S6-1, and S6-2.

III. MAGNETIC FILM ENGINEERING

A. Fine-Line Etching for Pressure Connectors

Operationally useful fine-line etched conductor patterns for pressure connectors for thin film memory have been produced using the following procedures:

- (1) Precision master conductor patterns are scribed full size in Eastman Kodak Scribe Plate using diamond scribing tools on a modified and semiautomated Haag-Streit Coordinatograph Layout Table.
- (2) Cleaning of scribed master patterns is done in flowing, membrane-filtered (1.0 micron) ethylene dichloride while brushing gently with a 2-inch wide soft camel hair brush.
- (3) Photoexposure of emulsion-coated substrates is accomplished by passing collimated ultra-violet light through the scribed master with the master separated 0.025 inch from the substrate surface. The master is thus protected from damage through contact with the substrate.
- (4) Etching is done in a conventional ferric-chloride etching bath with the exception that the surface being etched is continually brushed with a 2-inch wide soft camel hair brush to remove etching residues which tend to cause "shorts."

- (5) All solutions used for developing, etching, cleaning, etc. are membrane filtered to a level of at least 1.0 micron and in some cases to a level of 0.45 micron. All critical work is done in clean benches or in a clean room.
- (6) "Shorts" which do occur are "scribed out" using a diamond cutting tool mounted in a machine designed and built specifically for this purpose.
- (7) "Opens" occur usually because a speck of dust was present on the master or on the emulsion surface during exposure. These are successfully repaired by a technique of microplating wherein a drop of electrolyte is suspended from a copper wire anode and allowed to touch the conductor where a break or partial break exists. With the conductor as the cathode, a current of a few micro-amperes is allowed to pass through the drop for a few minutes and copper is electroplated into the gap restoring the line to full conductivity.

An initial yield of 50 percent was achieved for patterns 8 inches long and 1.6 inches wide with 3-inch long and 0.002-inch wide conductors with 0.002-inch spaces. This yield was increased substantially by repairing "shorts" and "opens" with the methods described.

B. LCM Memory

The prototype memory stack has been assembled with a full complement of ten word pieces, four of which have magnetic parameters and line etching adequate for test purposes. All word address and driver circuits are installed and operating. A full set of eight digit-line pieces has been installed, one pair of which is equipped with six digit card connectors, two located at the center of the pieces and two at the edge. Two digit cards of four channels each are available for use at these locations. Word-noise tests show an adequate signal-to-noise ratio at most available combinations of word address and digit location. High noise at some addresses is under investigation.

C. LCM Memory Stack

The construction and assembly of stack components did not reveal any major mechanical problems; however, a redesign of the diode array-pressure connector units is being investigated in hopes of reducing the large number of hand production steps presently required. Another problem which remains to be solved satisfactorily is the production of digit lines having excellent edge definition. Since we are using copper clad fiberglass, surface roughness precludes scribing of the photoresist, and standard photoexposing techniques must be used. Great care is required to eliminate imperfections caused by dust in digit line edges.

A complete visual inspection of ten word substrates, whose lines were generated by the scribing in photoresist and etching method, yielded the following average numbers of partial shorts and opens. (Percent open indicates hole size relative to linewidth.)

<u>Percent Opens</u>	<u>No. per Substrate</u>
100	5
80	7
60	7
40	21
20	45

Percent Shorts

100	28
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In comparison with other techniques, these are excellent results and appear to be satisfactory from a practical standpoint. The shorts, of course, can be scribed out, requiring approximately two minutes per short removal. The substrates were scribed automatically at the rate of three per eight-hour day, and the process seems well suited to production.

D. LCM Magnetic Film Specifications

Tentative specifications have been determined based on spot checks of ten arrays in the LCM Tester II. They are H_c (MIN), 12 oersteds; H_k (MAX), 10 oersteds; $(H_k \alpha_{90})_{MAX} = 3$ oersteds; magnetic film thickness 1200 Å, and copper thickness 40 kÅ. Corresponding digit and word currents are 150 to 200 ma and 500 ma, respectively. These characteristics have been obtained in annealed 83 percent Ni, 17 percent Fe, or unannealed 10 percent Co, 72 percent Ni, 18 percent Fe, films. The latter have less dispersion.

E. Content-Addressed Memory

The test equipment has finally been upgraded to evaluate one mismatch bit in the presence of many match bits. The initial result was to show an asymmetry in match signals of opposite polarity larger than the available margins. The presumed cause was excessive locking due to high dispersion; this is believed cured by slightly lowering the deposition temperature. Several films that were recently made and tested appear to have small but adequate margins for all except a few defective bits. The words containing these bits could be wired out at the assembly of the memory.

F. Saturable Shielding

The computer program for simulating shielded thin-film memory structures has been improved. It is now faster and can model the wall switching as well as the uniaxial rotation of the films.

Three samples of memory cells employing 0.005-inch square shields have been fabricated and are being tested.

IV. SYSTEM PROGRAMMING AND APPLICATIONS

A. Graphical Service System

Work during this period has concentrated on a new version of CORAL called CORAL II. A number of routines have been written and are to be checked out. CORAL II is considerably simpler than the existing CORAL since many exotic, unused and time-consuming features have been dropped. Implementation of a CORAL II programming language is planned as an extension to the ALGOL being created in VITAL. Productions for the CORAL II operators have been worked out and will be added to ALGOL soon.

Work on a new display executive and real-time input monitor has been started. The VITAL production loader and languages will be used to make the GSS controller, and CORAL II will be used to make the action routines. The major job remaining is to collect the scattered results of the past six months' efforts and to assemble them into a coherent system.

B. Mk 5

Several major new facilities were incorporated into Mk 5, the time-shared assembly language programming system of the TX-2 computer.

A display scope editing facility, called EDIT, has been implemented in Mk 5. EDIT enables a user to obtain a "partial listing" of the program's source text on his console display scope, edit the text by inserting or deleting characters, and then incorporate the changes into the source program. A somewhat different capability of EDIT provides a "partial listing" of the source text and its binary equivalent on the display scope.

The display capabilities are available via a metacommand which displays the actual contents of program and machine state registers after an error alarm or trap interruption. Hence, a Mk 5 user now has three sources of output from Mk 5: typewriter, Xerox, and display scope.

A tracing feature has been added to Mk 5. When it is activated, all user jumps and skips are published as a pair of symbolic addresses separated by the "hand" character. The first address is the location of the jump or skip instruction and the second address is the location to which the jump or skip has passed. When used in conjunction with meta-bit trapping, the trace provides a very powerful debugging tool. Work has begun on a program to display trace information as a FLOW-MAP which will provide a much broader debugging capability than has been heretofore available.

A facility for finding uses of a given symbolic identifier within a user's program has been incorporated into Mk 5. The output is a list of the names of the program lines containing the identifier, and optionally, the actual lines themselves.

A file-turning capability was implemented in Mk 5. This enables Mk 5 to accommodate very large source programs, even those for which not enough core is available. The amount of core used for each program is dynamically controlled by Mk 5 and is based upon the amount made available by the APEX core storage allocation routine, CSAR. Since file-turning is time consuming, service from Mk 5 is slower when operating on large source programs.

To assist in the debugging of Mk 5, a program has been written which produces a Xerox dump of the state registers, index registers, and information about the files set up in the APEX map stack. Although this was produced specifically for debugging Mk 5, it is available as a public program in APEX for other uses.

C. Waveform Processing

A new theoretical understanding of nonlinear systems¹⁻⁵ has provided a systematic basis for the nonlinear processing of signals. It is now possible to design systems to process signals which can be modeled as a generalized superposition of elementary functions. In contrast, linear systems presuppose an additive superposition of elementary functions which are usually sinusoidal or exponential.

In the previous quarter an experiment to demonstrate a practical application of a nonlinear filter based on the new theory was carried out successfully. The signals that were processed were selections of ordinary music and speech.

It was hypothesized that music and speech can be modeled as a product of two signals: a slowly varying unipolar envelope or intensity function and a rapidly varying bipolar "carrier" or characteristic function. The objectives of the filtering experiment were to isolate these

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components as well as possible, to modify the envelope function by attenuation or amplification, and then to recombine the resulting components. The practical effect desired was that of volume compression or expansion.

The system was simulated by means of a digital processor and selections of speech and music were processed. Separate samples of output signals were obtained for the following:

Percent Volume Compression	
Music and speech	100
Music	75
Percent Volume Expansion	
Music	25
Music	50

The resulting signals were played through a very high quality audio reproducing system with extremely favorable results. An audio tape record was made of these results. When measured by a standard VU meter, the 100 percent volume compressed music was measured at constant volume with ± 1.5 VU throughout its entirety.

In addition, the envelope function was isolated and as a final check upon the performance of the filtering system, this envelope function was multiplied by the 100 percent volume compressed music in order to reconstitute the music. When compared in listening tests, this reconstituted music was observed to be subjectively indistinguishable from the original music.

REFERENCES

1. A. V. Oppenheim, "Superposition in a Class of Nonlinear Systems," TR-432, Research Laboratory of Electronics, M.I.T. (31 March 1965).
2. _____, "Superposition in a Class of Nonlinear Systems," 1964 IEEE International Convention Record, Part 1, p. 171 (1964).
3. _____, "Generalized Superposition," Quarterly Progress Report No. 72, Research Laboratory of Electronics, M.I.T., p. 176 (15 January 1964).
4. _____, "Optimum Homomorphic Filters," Quarterly Progress Report No. 77, Research Laboratory of Electronics, M.I.T., p. 248 (15 April 1965).
5. _____, "Nonlinear Filtering of Convolved Signals," Quarterly Progress Report No. 80, Research Laboratory of Electronics, M.I.T., p. 168 (15 January 1966).

COMPUTER COMPONENTS GROUP 24

I. MAGNETIC FILMS

A. Anisotropy Spectrum of Magnetic Films

Preliminary experiments to excite individual uniaxial anisotropy relaxation processes by means of a rotating annealing field, discussed in the last Quarterly Technical Summary,^{*} have been successfully performed. A relaxation peak tentatively identified as process 2 (activation energy = 0.34 eV) measured previously by Smith, Weiss, and Harte[†] was observed at 155°C and 4 mHz. Two techniques were tried: temperature sweep at fixed frequency and frequency sweep at fixed temperature. Although both appear to work, the latter is preferred since the magnitude of the contribution to the anisotropy from the various processes depends on temperature. A systematic study of relaxation processes in a variety of film materials is now being planned over a frequency range of 50 μHz to 1 Hz.

B. High-Resolution Lorentz Microscopy

Although the technique of Lorentz microscopy has been known for several years, quantitative studies of the magnetization-ripple spectrum in magnetic films have not been carried out due to the lack of high resolution. High resolution requires: (1) use of the objective lens for the first stage of magnification and (2) illumination by a pencil of electrons having low angular divergence. Apparatus has been built for our microscope (RCA EMU3) which permits placement of the specimen at the objective lens; to obtain low divergence illumination, a pointed-filament gun technique is being tried.[‡] Since pointed filaments are not available from RCA, the microscope has been modified to permit installation of a Siemens gun, for which pointed filaments are available. In addition, it is planned to use the aperturing technique of Speidel[§] in order to further decrease the angular divergence.

C. Switching of Ultra-Thin Films

An extensive theory of the role of spin waves during high-speed magnetic film switching has been developed. An experimental test of this theory requires the use of ultra-thin films (thickness $\lesssim 100\text{\AA}$). For such thin films new experimental methods are required in order to observe switching and work has started on an experiment to use the Kerr magneto-optical effect for this purpose. A pulsed ruby laser with an output of ~20 megawatts is being used as the light source. Several difficulties have been encountered in synchronizing the light and

^{*}General Research Quarterly Technical Summary Report, Lincoln Laboratory, M.I.T. (15 May 1966), DDC 634819.

[†]D. O. Smith, G. P. Weiss, and K. J. Harte, *J. Appl. Phys.* 37, 1464 (1966).

[‡]Y. Sakaki and G. Möllenstedt, *Optik* 13, 193 (1956).

[§]R. Speidel, *Optik* 23, 125 (1966).

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switching pulses. The most stable Q-switching is to use a Pockels-cell shutter to open the light path to permit lasing with a resultant jitter in the light pulse of ~ 1 nanosecond. A mercury relay will be used to open the Pockels-cell shutter and simultaneously send a current pulse to a strip line to switch the film.

II. OPTICS

A. Magneto-Optics

The conditions for maximizing the longitudinal magneto-optical mode conversion in transmission or reflection have been calculated to first order in the magneto-optical constant for structures consisting of a magnetic film sandwiched between multilayer dielectric structures. For birefringent incident and exit media oriented so that the converted mode cannot reflect, the loss function for that mode can be made to approach zero by proper choice of the dielectric structure. As a consequence, the transmission mode conversion can approach unity. High-efficiency reflection conversion requires the use of a lossless birefringent film in the upper dielectric structure. The $||$ -mode elements of the characteristic matrix of a birefringent film are found in general to be complex, in contrast to the real diagonal and imaginary off-diagonal elements of a lossless isotropic film. By means of such complex matrix elements, and even for a mode which transmits in the incident medium, the corresponding loss function can be made to approach zero, again with the consequence that the conversion efficiency approaches unity.

B. Optical Phase-Shifter

The theory of the thin film electro-optical phase shifter has been extended to include loss; as a first step in building such a device, single crystal CdS films have been grown and electro-optical effects have been experimentally observed.

C. Thermo-Optics

The fabrication of hardware for thermo-optical writing of information into an ultra-thin magnetic film is essentially completed and assembly is in progress.

III. ELECTRON TRANSPORT

A. Triode Measurements

DC measurements of thin film tunnel triodes in the grounded base (middle film) configuration have in some cases yielded an indication of activity. This activity, which is manifested as a difference between forward and reverse small signal parameters $(g_f - g_r) \neq 0$ or $(r_f - r_r) \neq 0$, is difficult to measure, however, due to the shorting effect of the emitter base or collector base diode at high bias voltage. An AC small-signal g-parameter measurement has also been attempted using operational amplifiers to provide a low impedance current monitor. This measurement failed due partly to the above shorting effect and partly to the small size of the signal to be measured. At present a bridge technique is being attempted which holds promise of success.

IV. ADVANCED CIRCUITS

A. Magnetic Writing-Table

Assistance was given to Group 23 in developing a magnetic writing-table for possible use as an input for the TX-2 computer. In its present form this table makes it possible to draw over an area of 1 square foot with a pen or probe and read out digitally with 10-bit resolution for each X and Y coordinate at a rate of 30 samples per second. The principle involves the sensing of a null at 60 kHz with a magnetic probe. The null is caused to shift linearly across the active area in 16 msec and the digital output is obtained by examining a counter at the time of null.

PSYCHOLOGY GROUP 25

I. USE OF COMPUTERS ON-LINE

A. APEX

APEX is the executive system that time-shares the TX-2 computer. The central parts of the system, those having to do with file maintenance and with time- and memory-sharing, are complete and have been operating without serious troubles throughout the past quarter. The peripheral parts of the system, those having to do with input-output operations, are in various stages of development or operation. Enough of them have been operational throughout the past quarter to handle most of the TX-2 applications.

The effort on the basic system has been limited to troubleshooting and to cleaning up loose ends. Work has continued on the routines for IBM magnetic tape and the Xerox printer. The magnetic tape routines require some further work, but the printer routine is nearly ready. It will replace the present version and will provide more extensive buffering (via the Fastrand drum) and will impose a smaller load on the computer while actually producing output.

An analog-to-digital input routine has been developed for APEX by members of Groups 23 and 62. It allows speech or other audio-frequency waveforms to be sampled and transferred to the Fastrand drum during normal time-shared operations of the computer. This capability, not common in time-sharing systems, will greatly facilitate the waveform processing that is of interest to a considerable fraction of the TX-2 user community.

As the system approaches completion, the group's effort is being reduced and redirected to discussions of proposed extensions and improvements. Detailed plans now exist for a multiplexed data-link input-output facility for APEX and for a new and improved package for the scope, light pen, and wand. Coding has been undertaken by members of Group 23 and by subcontractors. Changes to the user-switch algorithm have also been studied.

B. Lincoln Reckoner

The Lincoln Reckoner is a time-shared facility for numerical computations that is based on the APEX system and is intended for on-line use by scientists and engineers.

Improvements and extensions were for the most part suspended, awaiting the results of the test described below, but work continued on a small procedure-oriented language designed to fit into the system.

1. Users' Test of the Reckoner

The "field test" discussed in the previous Technical Summary^{*} was completed. Six of twenty scientists and engineers introduced to the Reckoner during the test period made substantial use of the facility. They worked on absorption of oxygen by aluminium, theoretical

* General Research Quarterly Technical Summary Report, Lincoln Laboratory, M.I.T. (15 May 1966), DDC 634819.

calculations in plasma physics, modeling the inner ear, evaluation of war-game data, error analysis of a satellite navigation system, and simulation of Tradex radar data analysis. All six made extensive use of the procedure-building feature, by which a series of operations may be concatenated into a single operation. Three made extensive use of the graphical displays. The three non-programmers, as well as the three with programming experience, were able to start making use of the system with roughly one hour of experience. In ten to twenty hours of time-shared console time, each felt he had gained new insight into his problem.

Several of the twenty potential users had to be told that the Reckoner was not adequate for their current problems. The main deficiencies were in facilities for input of data in bulk, for algorithms with elaborate conditional branching, and for boolean algebra on the scale needed in coding theory. But within its area of competence, even now the TX-2 Reckoner fills a need for the scientist or engineer who has a numerical problem to explore. A journal article, a Laboratory Memorandum, and a letter to the editor of a journal have already resulted from the test.

2. Documentation

An effort has been started to document the system properly. A paper explaining the Reckoner and the thinking behind it has been written,* and a reference manual on the use of the system is being prepared. The manual has two parts: one attempts to give an exact description of each library routine from the user's viewpoint; the other gives general information not specific to any one routine.

C. User Services on the IBM 360

Planning has begun on two user-oriented services for the time-shared IBM computer that the Laboratory will have. One is similar to the present TX-2 Reckoner. The other is a general editing service that will handle, among other things, text. Specifications have been drawn up and are being discussed with potential contractors.

II. HUMAN INFORMATION PROCESSING[†]

A. Discrimination of Recency

An experiment has been performed to see whether a composite stimulus consisting of a picture of an object with the name of the object printed beside it would have a subjective recency different from that of the picture alone or the word alone.

Using words as test stimuli, and words or composite items as inspection stimuli, the expected result was obtained: the apparent recency of the composite was greater than the apparent recency of the word. But using pictures as test stimuli, and pictures or composites as inspection stimuli, at some intervals between inspection and test the apparent recency of the composite was less than the apparent recency of the picture. It was almost as if combining a picture and its name decreased the apparent recency of the picture and increased the apparent recency of the word.

* A. N. Stowe, *et al.*, "The Lincoln Reckoner: An Operation-Oriented, On-Line Facility with Distributed Control," Meeting Speech 1678, Lincoln Laboratory, M.I.T.

[†]One of the investigators was a National Institutes of Health postdoctoral fellow.

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A further experiment is being done to see whether these phenomena can be explained in terms of the way a composite stimulus is encoded in memory.

B. Application of the Discriminant Rule to a Memory Task

In earlier work, a Discriminant Rule has been proposed to describe the effects of context on the identification of words heard in noise.* The rule attempts to specify how the probability of a correct response will increase when the context limits the subject to a smaller number of alternatives. An extensive retabulation of an old set of data on keeping track of the states of several variables[†] has been made to see whether the same rule could be applied to them. In some conditions of the experiment, the set of responses available to the subject was limited by his knowledge that some variables could never be in some states. The Discriminant Rule gave a very satisfying account of the way in which the probability of correct response depended on the number of alternatives available to the subject. It is striking that a rule borrowed from psychophysics should give such a good description of response selection in a memory task.

* A. N. Stowe, W. P. Harris, and D. B. Hampton, "Signal and Context Components of Word Recognition Behavior," J. Acoust. Soc. Am. 35, 639 (May 1963).

† D. B. Yntema and G. E. Mueser, "Remembering the Present States of a Number of Variables. III: Why It Is Difficult to Keep Track of Several Variables with the Same Set of States," Group Report 58G-0013 (17 August 1960), DDC 242283.

COMPUTER SYSTEMS GROUP 28

I. COMPUTER CENTER DEVELOPMENT

The interim configuration of the IBM System 360/67 was delivered on 31 May 1966 and made available to the Laboratory for test operation in mid-June. Operations were quickly shifted from the installed 360/65 to the Model 67's, allowing the former to be released on 28 June. As is to be expected with such a large new system, many hardware bugs have to be shaken out. There is therefore almost continuous field engineering activity in both checkout and design modifications. Because of the partitioning capability and duplication of components in the system, however, it is usually possible to continue programming operations on one processor while the other is used for the field engineering work. The final devices needed to complete the Model 67 configuration (i.e., drum, multiplexor channels, disk switch, etc.) will be delivered and installed during August and September. This will be done on weekends in order not to interrupt the work flow. The 360/40 core memory was doubled during July to accommodate the large peripheral and data gathering role being taken on by this system. An additional card reader punch unit will also be added in August.

With the availability of the Model 67's, the third and last 1401 system and the 7094-11 system were released on 31 July 1966. The 7094-11 was originally installed at the Laboratory in November 1960 as a 7090. It was field modified twice to reach its final configuration as a 7094-11. In nearly six years of operation by the Laboratory, it has provided over 23,000 hours of computation, or an average of about two full shifts per month.

Operating System/360 has now become the standard programming system for the Laboratory. Like the hardware it still has to be thoroughly shaken out. From the point of view of programmers converting from the 7094, a major roadblock was overcome when a large version of Fortran became available in July. This removed the previous size limitation of about 250 input statements. Again, like the hardware, Operating System/360 is under continuous correction and improvement. However, it has reached a point where it should be able to handle any job required by the Laboratory's commitments.

II. HYBRID COMPUTATIONAL FACILITY

The entire hybrid facility is now complete. Extensive testing, using the LINC to control the DDA has shown that failures occur in the core memory system of the DDA. A memorandum has been prepared to show in detail what kinds of failures exist. It appears that cross-talk between the sense circuits for certain bit patterns causes extra "ones" to appear in certain memory locations. Discussions with the manufacturer of the memory system are being conducted to decide what modifications are necessary to correct the trouble.

RADIO PHYSICS DIVISION 3

INTRODUCTION

This section summarizes the General Research efforts of Division 3 for the period 1 May through 31 July 1966. A substantial portion of the Division's activities is devoted to the PRESS Program, reports for which appear in the Semiannual Technical Summary Report and the Quarterly Letter Report to ARPA.

S. H. Dodd
Head, Division 3
M. A. Herlin
Associate Head

SURVEILLANCE TECHNIQUES GROUP 31

Group 31 maintains and operates the Millstone radar system and the Haystack research facility at the Millstone Hill Field Station. The group conducts radar research programs which are currently emphasizing observation of the moon and planets. Significant programs in the development of satellite observation techniques, in the study of the upper levels of the ionosphere, and in several aspects of radio astronomy are also being carried out. Programs in cooperation with other groups are also in progress in the areas of space communication research and active and passive interferometer techniques.

I. OPERATION, MAINTENANCE AND IMPROVEMENTS

A. Millstone Radar

The Millstone L-band radar was used in satellite tracking programs, lunar studies and ionospheric backscatter measurements during this reporting period. No planetary observations were made. Satellite tracking included the usual one-day-per-week concentration on Space Defense Center priority objects, the MITRE/Millstone interferometer and a number of special test operations for checking out new computer programs.

All of the computer functions necessary to the operation of the radar were transferred to the SDS-9300 by the end of the period and operations on the CG-24 computer terminated. No unusual maintenance problems in the radar were encountered during the period.

Two improvements worthy of mention were completed.

- (1) A system for lowering the subreflector to a cradle on the monopulse feed horn support was installed. This system, which was designed by Group 71, provides access to the focal point of the 84-foot dish, thus permitting radiometer observations over a wide range of frequencies. A provision was also made to change focal-point feeds easily.
- (2) A three-channel cooled parametric amplifier designed in Group 46 was installed in the radar tracker. This system provides low noise front ends for the sum channel and the two error channels.

B. Haystack Research Facility

In this reporting period the Haystack antenna was used for 905 hours of observations; additionally, a total of 370 hours was expended in maintaining and improving the system. Radio astronomy observations included spectral line, OH interferometer, and quasar measurements. The Haystack radiometric system was also used to process 400 MHz data taken with the Millstone antenna. Both planetary and lunar radar observations were made. The radar scattering characteristics of Venus and Mercury were measured as part of a continuing study.

An improved master control console for the antenna was installed. Major changes in the transmitter cooling equipment and the control system have been made to provide greater operating flexibility and reliability. A new radar sequencer is in the final assembly stage. The sequencer will provide all timing functions required to obtain high resolution ranging measurements of planets and the moon.

C. Haystack Planetary Radar Development

The assembly of the Haystack Planetary Radar System is nearing completion, and the box was moved to the Haystack facility on 28 July for final testing prior to installation on the antenna. The traveling-wave maser has been accepted and is operating successfully at Haystack. The first two klystrons to be used in the 500-kW X-band transmitter have been proof-tested at the manufacturer's plant. The beam control unit required for the klystron amplifier is the only item which will be delivered late; however, this should not delay the initial turn-on of the Planetary Radar System.

All subsystems installed in the Planetary Radar Box are currently being checked at Haystack. The box will move onto the antenna for additional testing in September. The interface into the CDC 3200 to permit real-time data transfer is complete and the phase detectors required for the processing of the received signal are in the final assembly stage. Real-time processing programs for the high-accuracy ranging measurements required in the initial application of the Planetary Radar System are nearing completion.

II. SPACE SURVEILLANCE

A. Orbit Upgrading

All of the elements in the contract with TRW Systems for an orbit determination program have now been received. Tests on the full integration of these programs into the complete radar system are continuing. Portions of the package are now operational.

Two additional programs were obtained from MITRE and put into operational use during the quarter. One of these generates look angles and the other a schedule of observing. Both work from satellite elements as input, and provide useful checks on the TRW programs.

B. Tracking Support

Of 111 satellite passes observed by Millstone in this quarter, 42 represented priority objects for the NORAD Space Defense Center. The rest were used for checkout of the orbital upgrading programs described above. The radar was also used to assist NASA in evaluating the success of PAGEOS, the large spherical satellite launched 24 June 1966. Data on the first five revolutions were sent to NASA, and were useful in establishing that full inflation had in fact occurred.

III. LUNAR STUDIES

Radar observations continued during the quarter both at 23 and 3.8 cm. In addition, a series of radiometer observations was started at 3.7 cm. The second quarterly progress report* in the NASA supported lunar observation program was issued on May 15.

A. Millstone Observations

The last set of depolarization observations involving linear transmitted and received polarizations was completed and the results of the experiments in completely specifying the mean scattering properties of the moon at 23 cm are being prepared for publication. A program has

* Quarterly Progress Report No. 2, Radar Studies of the Moon, Lincoln Laboratory, M.I.T. (15 May 1966).

been started for unambiguous mapping of the lunar surface at 23 cm by super-synthesis coherent techniques. If successful, the method will be used to further extend polarization experiments against anomalous localized regions of the lunar surface.

B. Haystack Radar Observations

Several runs of radar observations have been made at 3.8 cm to collect data for testing the various computer programs designed for high resolution mapping of the lunar surface as well as to initiate contrast mapping in the lunar equatorial regions. Certain problems prejudicing the accuracy of predicting the Doppler frequency shift have been encountered and have been the subject of intensive work. The actual mapping programs, however, are complete and in use.

C. Haystack Radiometer Observations

High resolution studies of the phase variation of the thermal emission from the moon at 3.7 cm have been started. The experiments are carried out in the form of drift scans with two orthogonal linear polarizations to provide simultaneous polarization information. The results will be presented directly from the computer as contour plots.

IV. HAYSTACK PLANETARY STUDIES

A. Venus

Radar cross section measurements of Venus were made on five days spaced at intervals of about two weeks during May and June. None were made in July because of scheduling conflicts. The cross section rose from 1.3 percent on 5 May to about 3.3 percent on 28 May but by 27 June had fallen to about 1.3 percent again. At the end of June the total echo power (about -210 dbw) was approaching the limit of detectability of the present Haystack radar system.

B. Mercury

Observations of Mercury were attempted on three days at the end of July around the time of inferior conjunction. Equipment malfunctions and extremely bad weather rendered much of the observing time valueless, but enough data were gathered to obtain a measure of the cross section (about 5 percent as determined previously) and to provide a fairly good signal spectrum from which the scattering law may be established with better accuracy than previously.

C. Shapiro Test of General Relativity

The software and hardware phases of the program which is planned to enable Haystack to observe Venus and Mercury at superior conjunction are rapidly reaching their climax. All elements will have been individually tested by 1 September, and should be ready for combined testing on the moon shortly thereafter. No serious problems have appeared to date.

V. ATMOSPHERIC STUDIES

A. Ionosphere

Backscatter observations are continuing as planned. The analysis of the 1964 results is complete and will form the basis of a journal article. In sum, it appears that the behavior observed

Division 3

in 1964 is remarkably similar to that observed in 1963 and described by Evans.* This is to be expected during the years of minimum sunspot activity, but is nevertheless gratifying to find.

The L-band spectrum observations for 1964 have been analyzed, and used to provide average daytime temperatures in the height range 140 to 230 km, i.e., in the F1 region (which is inaccessible to the UHF vertical-looking radar. It has also been possible to determine the ratio of light (i.e., O^+) to heavy (i.e., $O_2^+ + N_2^+ + NO^+$) ions in this altitude range to yield results which are in reasonable agreement with the few published rocket determinations of ion composition in this region. The prospect of being able to perform a synoptic study of ion composition in the F1 region is extremely exciting and suggests the need for increasing the capability of the L-band radar system so that these measurements can also be made at night. A second journal article is in preparation which will describe the spectral work.

VI. RADIO ASTRONOMY

A. Radiometric Observations

From 1 May to 31 July 1966 the principal radiometric observations consisted of flux density measurements of a number of discrete radio sources at 2 and 3.75 cm. The 2-cm fluxes of 3C273, 279, 48, and Virgo A appear to have increased within the last several months; 3C273 has more than doubled. These flux increases are markedly greater at 2 cm than at 3.6 cm. Careful observations of beam shape and antenna efficiency of the Haystack reflector throughout this period exclude any significant instrumental effects. Measurements with the well-calibrated cornucopia antenna provide additional evidence of the reality of the flux increases. Measurements have also been taken at 2 cm as preparation for a map of the galactic center. A series of 2-cm flux measurements of Venus have begun and will continue throughout the Venusian year.

Observations of the OH emission sources continue in right and left circular and linear polarizations. The sources near NGC6334 and W75 at 1665 MHz show no long-term time variations.

Modifications to the Radar/Communications receiving system have permitted attempts to improve observations of the 94α hydrogen transition in the tenuous lagoon nebula where this line has been detected marginally. A search for the red-shifted 90α hydrogen line in the quasar 3C273 has been unsuccessful.

B. OH Interferometer

The OH interferometer went into operation in early June. The first few days of observing were used to determine the baseline parameters from continuum radio sources of known position. The interferometer was then used to map the OH emission regions of W3, W24, W49, and NGC6334. W3 and W24 appeared to be single point sources while W49 and NGC6334 appeared to be double sources within the resolution possible with the Haystack-Millstone baseline. An upper limit to the angular size of the OH emission sources has been set at 20 seconds of arc. Positions to within 10 seconds of arc were also obtained for the emission points. Theoretical work is progressing but a satisfactory physical model which explains all the characteristics of OH emission has not yet been found.

* J. V. Evans, *Planet. Space Sci.* 13, 1031 (1965).

RADAR DIVISION 4

INTRODUCTION

This section summarizes the General Research activities of Division 4 during the period 1 May through 31 July 1966. The major portion of Division 4's activities is devoted to Radar Discrimination Technology, PRESS, BMRS, and Space Communications, which are described in separate reports. The General Research activities in Division 4 are carried out by Group 46, which is engaged in work on Haystack instrumentation, millimeter radar, and microwave component development.

J. Freedman
Head, Division 4

H. G. Weiss
Associate Head

DIVISION 4 REPORTS ON GENERAL RESEARCH

15 May through 15 August 1966

UNPUBLISHED REPORT

Journal Article

JA No.

2758 RF Generated Shock Waves R. M. Weigand Accepted by Proc. IEEE

MICROWAVE COMPONENTS GROUP 46

I. INTRODUCTION

Group 46 contributes to the radar program through direct participation in specific projects, and through a program of general research which is closely related to the microwave requirements arising from radar projects. Contributions are made to the General Research Program through the support of Haystack Hill, operation of a high-power microwave laboratory, development of low-noise receiver techniques and receivers for space communications, participation in a millimeter-wavelength program, and studies of very-high-gain antennas and antenna feeds.

II. HAYSTACK MICROWAVE COMPONENTS

A. Planetary Radar Box

Construction and final assembly of the Planetary Radar Box and its components are nearing completion. Transmitter calibration and balance tests were performed at the High-Power Laboratory using VA-849 AM klystrons. These tests showed phase and amplitude balance could be achieved easily so that no significant antenna pattern distortion should be encountered. The box and receiver components have been moved to the Haystack site where final assembly and checking of all interfaces is now in process.

1. Transmitter

All high-power transmission lines from the klystrons to the dummy loads have been installed and checked. These lines and the related network of couplers, etc., have been adjusted to achieve equal lengths in each of the four transmission lines and maintain symmetry in the monitor and feed lines. The calibration of all couplers was checked and found to be within ± 0.1 dB of the manufacturer's calibration and well within specifications.

In the upper channel the maximum unbalance between right- and left-line couplers is -30 dB; in the lower channel the maximum unbalance is -40 dB. With a signal of equal phase and magnitude in all four lines, nulls of -30 dB or deeper are indicated at the phase balancing monitor points. Harmonic filters in all but the drive monitors and the spectrum analyzer ports reject second and third harmonics by 45 dB.

Final calibration of the monitoring system will be performed after installation of the antenna feed horn which is the determining element in the phase balance of the lines.

2. Crystal Power Monitors

All crystal detectors and operational amplifiers have been received. The crystal detector-operational amplifier units are being assembled and calibrated.

Division 4

3. High-Power Circulators

High-power tests have been completed successfully on all ferrite sections of the five circulator bodies at a level of 75 kW per channel. Short-slot couplers and folded H-plane tees of OFHC with attached water-cooling coils have been assembled on two bodies. The vendor has balanced the phase shift sections. The complete circulators with a 150-kW capability will be tested next at high power.

4. Maser

The traveling-wave maser system has been delivered and operated successfully in the Laboratory. The maser, dewar and RF pump box have been mounted on the maser stand and wired for remote operation. The assembly is now ready for installation in the Planetary Radar Box. The characteristics of the maser are listed below:

Signal frequency	7840 MHz
Pump frequency	20,640 MHz
DC magnetic field	3460 gauss
Gain	30 dB
Bandwidth (3 dB)	22 MHz
Input saturation power (for 0.5 dB gain compression)	-68 dBm
Gain instability - short term, 5 min.	0.05 dB
Gain instability - long term, 8 hrs.	0.15 dB
Gain instability during motion ($\pm 45^\circ$ from the vertical)	<0.20 dB
VSWR (input and output)	1.20:1
Noise temperature	8.0 \pm 2.0°K
Operating time (on one fill of liquid helium)	15 hours

III. SOLID-STATE AMPLIFIERS

A. X-Band Parametric Amplifiers

An X-band parametric amplifier, designed for low-noise performance without cooling, has been undergoing electrical tests and modifications. At a frequency of 7.5 GHz and gain of 20 dB, the amplifier has a 3-dB bandwidth of about 100 MHz and a noise temperature of less than 110°K. The stated noise temperature is for the paramp alone; in actual operation, it would be necessary to allow 20 to 30°K more to account for circulator and second-stage noise contributions. The noise temperature was measured by the Y-factor method, using a calibrated cold load at liquid nitrogen temperature and a room-temperature load, both of which were well matched and isolated from the paramp by an additional circulator before the paramp circulator. An effort is being made to further reduce the noise temperature of the parametric amplifier.

Another X-band, low-noise parametric amplifier of the same class has been designed. The amplifier has a 49-GHz idler frequency and a theoretical noise temperature of about 80°K, using present state-of-the-art diodes.

A general computer program has been synthesized which, with minor limitations, will completely design a low-noise parametric amplifier in any frequency range of the same general class as the ones described above.

A fourth parametric amplifier assembly of the type designed for direct immersion in a cryogenic bath has been fabricated for use at the Haystack site. The unit exhibits a receiver noise temperature of less than 40°K at 7840 MHz when operated in liquid helium.

B. Diode Packages

A new varactor diode package has been designed. The package is smaller than the ones currently employed and is made of glass. Its use should result in lower uncooled noise temperatures for the developmental X-band parametric amplifiers than those presently achieved. The delivery of experimental dummy packages from the Micro Optics Company is expected shortly.

ENGINEERING DIVISION 7

INTRODUCTION

The Engineering Division, in the quarterly period ending 31 July 1966, supported the General Research Program of the Laboratory by fulfilling mechanical design and fabrication responsibilities for a number of projects. At Haystack Hill, there was a continuing effort to upgrade the antenna drive and control system, and a parallel effort to outfit the Planetary Radar plug-in box with cooling equipment and microwave hardware. Solid state research was aided by the further development of a 300-ton press, a fluoride furnace, and unique optical apparatus. The lunar and laser radar projects required modifications to existing pedestals and the addition of control devices in their drive systems. Finally, an accelerated effort is being made to upgrade and combine several existing computer programs for the structural analysis of the radomes which are being proposed for very large antenna systems.

J. F. Hutzenlaub
Head, Division 7

DIVISION 7 REPORTS ON GENERAL RESEARCH

15 May through 15 August 1966

PUBLISHED REPORTS

Journal Articles*

JA No.

2583	Structural Analysis of the Haystack Antenna	W. R. Fanning	J. Struct. Div. ASCE <u>92</u> , No. ST 1, 431 (1966)
2732	Large Cross-Linked Polystyrene Slab Suffers Thermal Fatigue	E. B. Murphy	SPE J. <u>22</u> , No. 4, 53 (1966)
2754	Large Radar Shield Fabricated at Ground Level	P. Stetson	Civil Eng. ASCE <u>36</u> , No. 6, 42 (1966)

* * *

UNPUBLISHED REPORTS

Meeting Speeches†

1507	Mechanical Design of the Haystack Antenna	W. R. Fanning	Design and Construction of Large Steerable Aerials, London, 6-8 June 1966
1599	The Use of Sandwich Shells in Large Steerable Aerials	J. W. Mar F. Y. M. Wan	
1601	Performance and Design of Metal Space Frame Radomes	W. R. Fanning J. Ruze	

* Reprints available.

† Titles of Meeting Speeches are listed for information only. No copies are available for distribution.

MECHANICAL ENGINEERING GROUP 71

I. HAYSTACK

A. Planetary Radar (PR) Box

1. Air Conditioning and Water Cooling

All the plumbing for the main water-cooling assembly has been installed in the box and pressure tested, including the adapter lines necessary for the operation of the two VA-849 klystron tubes.

The five fan-coil units used for air conditioning the equipment have been installed and are now being tested and balanced using a 7.5-ton chiller unit.

2. Microwave Hardware

The VA-1949A magnets were received from Varian Associates and were installed in the carriage which supports the klystrons. The pole piece adapters that were received from Varian were reworked by Lincoln Laboratory to fit the VA-849 tubes. The carriage was then mounted in the box and the tubes boresighted to the RF axis. Addition of the ground plane, beam control base casting and shroud was made and then the entire unit was electrically wired into the PR Box. Minor bracket modifications were made to accommodate the waveguide runs. The transmit waveguide runs were modified to accept shorter circulators than those first planned.

The RF dummy loads and their associated waveguide runs and water cooling lines were installed. The final design of the dummy load calls for eight loads; however, only four were installed at this time because of the lower power levels of the VA-849 klystrons. The signal simulator and stalk chassis were designed and fabricated and are now being assembled with electronic equipment.

Because a change was made increasing the mechanical size of the electrically operated waveguide switches in the receiver lines, a redesign of these lines was necessary. This was accomplished, as well as the fabrication of the necessary waveguide bends and straight sections, to complete the assembly. The installation of the receiver assembly will take place as soon as the RF transmit tests have been completed. The larger switches also necessitated a modification to the attachment brackets on the maser dolly and the helium load.

The PR Box was delivered to the Haystack Site on 25 July 1966 for site integration and testing.

3. Special Handling Equipment

Two one-ton capacity, hydraulically operated, fork-lift type, straddle vehicles have been received for use with the Tube Carriage-Beam Control Assembly. These vehicles are used to facilitate the installation or removal of the tube assemblies from the PR Box.

Also, two supplementary handling frames have been fabricated. The first enables the Tube Carriage-Beam Control Assembly to be rotated 90 degrees to facilitate tube and top magnet removal. The other, a 180-degree rotating stand, permits tube separation from the magnet.

Division 7

4. Maser

The first maser for the RF box has been received at the Laboratory, fully tested by the Microwave Components Group (Group 46), and is ready for installation. This unit utilizes a batch liquid gas dewar. A second and third maser are being fabricated at the Microwave Electronics Corporation with delivery scheduled for the end of July and the end of September, respectively. The second unit will be used with a second batch liquid gas dewar which has already been received. The third maser will be incorporated with the second unit into a closed cycle refrigerator which is being readied by Air Products & Chemicals, Inc. Completion of the latter is anticipated in October 1966.

5. Site Modifications

Modifications to the cooling water, chilled water, and service lines have been completed at the box position on the antenna. The chilled water lines have been routed through the pump room to an area outside the radome building where two 7.5-ton chillers will be located.

A new box support frame was installed in the Test Dock No. 1 pit, permitting the PR Box floor to be on the same level with the Test Dock work platform, thereby facilitating the mobility of the tube handling vehicle. An overhead monorail has been installed which lifts the vehicle from the platform to the antenna tower floor.

Modifications have been completed on the antenna raceway catwalk. Side extensions were added to give full raceway width to facilitate the movement of personnel and equipment.

B. Blockage Reduction

The quadripod support structure for the secondary reflector is presently braced at its one-third points by $\frac{1}{2}$ -inch aluminum rods. These rods add approximately $\frac{1}{2}$ of 1 percent to the overall system blockage. A fiberglass rope with parallel strands is now being manufactured by Owens-Corning. This material in the smaller diameter would be electrically transparent at X-band frequencies. At the present time it appears feasible to replace the aluminum rods with a $\frac{1}{8}$ -inch-diameter fiberglass tension member.

The details of a test program have been worked out and fabrication of a test fixture has been started. Two 40-foot-long fiberglass tension members will be tested, one in a creep test under constant load, and the other in a stress-versus-temperature test at a constant length in an aluminum fixture. The creep test will indicate potential slackening with time of the cable. Since the cable has a different thermal coefficient of expansion than aluminum, the second test will provide data on potential stress variations in the Haystack radome environment.

The actual testing and analytical verification of the adequacy of this material should be underway during the coming quarter. If the tests are satisfactory, it is planned to install these new braces during the surface rerigging this fall.

II. MILLSTONE 84-FOOT TRACKER

The necessary equipment has been installed to modify the 84-foot-diameter Millstone tracker for the L-band interferometer experiments.

A permanent platform has been mounted behind the existing 10-foot secondary reflector, so that a single feed horn is at the focal point of the primary reflector. For the experiment, the secondary reflector assembly is lowered by means of two worm-gear winches, and is stowed adjacent to the main feedhorn housing by means of three "A" frame supports.

Coax and control lines have been installed from the platform equipment through the torque tube to the "doghouse" equipment shelter.

III. SOLID STATE RESEARCH

A. Materials Research

Studies were conducted on two aluminum alloys, 6061 and 7075, to determine the effect of various time-temperature and pressure treatments on the compressive strength of the alloys.

The materials were supplied in the T651 (i.e., stress relieved) condition and were, therefore, reheat-treated to the T6 condition in the form of 0.250-inch diameter by 0.300-inch long slugs.

The results showed that any form of swaging increases the compressive strength of the material and that the residual stresses will not affect nor be detrimental to their use in darts designed for re-entry signature studies.

B. 300-Ton Press

The Laboratory mobile press has been assembled and tested. The gauge load was compared against a calibrated load cell and showed a discrepancy of 1 percent over the total range.

C. Fluoride Furnace

Problems with drain tube, waterjacket and teflon coating have delayed delivery of the furnace. Preliminary tests have shown, however, that the furnace will be able to exceed the requirements for producing oxide-free fluoride laser material.

D. Ellipse-Hyperbola Mirror

Design of a mirror for the Optics and Infrared Group (Group 82) has been completed and fabrication is currently scheduled for August 1966. This lens incorporates an ellipsoidal and a hyperboloidal mirror. Templates for the tracer lathe are now being fabricated which will allow turning the unit in the Laboratory Machine Shop. A second fabrication approach is also being pursued which utilizes a tape controlled lathe.

IV. LASER RADAR

A telescope, originally manufactured by Diffraction Limited, Inc., for use in the Apollo Program, has been mounted on the Nike-Ajax pedestal at Millstone Hill along with the initial laser and telescope. All components previously reported as being on order or in fabrication have been received and mounted.

A second Nike-Ajax pedestal is being procured for a second-generation laser system. A five-inch diameter by 5-mm thick germanium optical disc has been ordered and delivery is expected by 3 September.

V. MILLIMETER LUNAR RADAR

A. Modifications

Design studies are underway to determine what modifications will be necessary to install shaft-angle encoders on both the elevation and azimuth axes of the lunar radar pedestal. It has become apparent that extensive alterations to the azimuth turret will be required to install an encoder on that axis. It will also be necessary to modify the existing cable-wrap and to change the azimuth buffer-stops to accommodate the reduced angle of rotation in azimuth.

B. Rotational Level Check

A rotational level check indicated the need for adjustment of the plane of the azimuth bearing. The adjustment has been made so that the azimuth turret is now within 20 seconds of true level in any position, with one exception: between a true heading of 250 to 270 degrees there appears to be a deviation where the angle of tilt is about 55 seconds. The cause of this deviation is not readily apparent and is being investigated further.

VI. STRUCTURES RESEARCH

The computer program entitled RADOMV which develops the vertices and beam member lengths for a space-frame radome has been placed in successful operation. The program has been used to design the random space-frame radome model which will be subjected to experimental buckling tests at M. I. T.

Using the STAIR program in conjunction with RADOMV, a stress analysis of a radome model has been performed for the anticipated loads required to buckle the model. This analysis establishes the beam dimensions necessary to insure that the model suffers a buckling failure before the yield stress of the frame material has been exceeded.

Plans are being made to use the FRAN program for a more precise determination of the stresses in the model space frame.

The major radome computer programs are being combined so that for an input of some 20 vertices and corresponding beam members, a complete 550-foot diameter space frame geometry will be developed, the stresses in each member determined, and the optical blockage of the entire frame assessed. Once this system is established, a variety of frame geometries, each with a range of beam dimensions, will be investigated to determine the most efficient radome design.

A study is now in progress to estimate the effect of differing beam lengths — with the corresponding cross-sectional dimensions as determined by a beam column stress analysis — on the optical blockage of the space frame. These results will be determined shortly.

CONTROL SYSTEMS GROUP 76

I. LASER MOUNT SERVOS

The Nike-Ajax laser mount at Millstone was modified to provide automatic tracking capability and to make control mode switching more convenient. In addition, a small azimuth-elevation mount was modified for installation on the Building D roof. This mount features automatic tracking and remote position control. Digital computer control of pointing angles will be added in the future.

II. HAYSTACK

Effort in this quarter was concerned with control console installation, antenna work, control system development, and reflector measurement and rerigging.

A. Antenna Drive

Antenna azimuth sticking was investigated. A short test was conducted which indicated symptoms of faulty hydraulic motor operation. Motor examination showed one bad motor with two cracked rollers. The other motor was torque-tested in the hydraulics lab and found to be normal. Two replacement motors were torque-tested and installed in the drive system.

B. Servo Control Valve

Special strain gages have been received. Instrumentation of the main spool for establishing force vs spool travel, using an X-Y plotter, is approximately 50 percent completed.

C. Hydraulics Laboratory

1. Hydraulic Test Stand

The stand has been unavailable as a result of room expansion, piping of chilled water, and stand relocation. Delivery of all temperature control gear is late. The electro-thermal reheat exchanger has been completed, wired, and is ready for stand hookup. The chilled water cooling stage has been completed and is in final stages of setup for the cooling performance test.

2. Motor Torque Test Table

This table is being modified with a small drive to facilitate unloaded tests of antenna drive motors. Through the use of strain gages, torque vs rotation plots are made which show piston fit, cam smoothness, and roller-bearing performance of a motor. Every motor is checked before installation and after removal from the antenna, and an X-Y plot of its performance is filed.

D. Main Antenna Control Console

This item was installed in the control room and brought up to the same level of control as had been achieved by the temporary console. Other auxiliary displays, controls, and communication will be brought into service as time permits. Drafting work has been started to provide electrical diagrams that describe the console and its tie-in with interface equipment.

E. Reflector Measurement and Rerigging

The camera test stand for the Photographic Data Collection System, intended for Haystack reflector measurement, is 90 percent completed. A contract was awarded for the camera mount spindle. Delivery is expected about 1 October 1966. Strobe lighting for this system was acquired.

Study contracts are in progress with two engineering firms to evaluate the potential of the Haystack antenna for rerigging.

SOLID STATE DIVISION 8

INTRODUCTION

This section summarizes the work of Division 8 from 1 May through 31 July 1966. A more detailed presentation is covered by the Solid State Research Report for the same period.

A. L. McWhorter
Head, Division 8

P. E. Tannenwald
Associate Head

DIVISION 8 REPORTS ON GENERAL RESEARCH

15 May through 15 August 1966

PUBLISHED REPORTS

Journal Articles*

JA No.

2613A	Automatic Potentiometric EDTA and Redox Titrations for Determinations of Stoichiometry	M. C. Gardels J. C. Cornwell	Anal. Chem. <u>38</u> , 774 (1966)
2633	A Note Concerning the Temperature Profile Within a Thermomagnetic Energy Converter	T. C. Harman J. M. Honig	Adv. Energy Conversion <u>6</u> , 127 (1966)
2672	Pseudobinary InSb-InTe System	A. J. Strauss M. D. Banus M. C. Finn	J. Electrochem. Soc. <u>113</u> , 458 (1966)
2698	Structure of Equations Specifying Operating Characteristics of Energy Converters Constructed of Anisotropic Materials	J. M. Honig T. C. Harman	Adv. Energy Conversion <u>6</u> , 149 (1966)
2762	Electron-Bombardment Technique for Deposition of CdS Film Transducers	R. Weber	Rev. Sci. Instr. <u>37</u> , 955 (1966)
2776	Efficient Visible Lasers of CdS _x Se _{1-x} by Electron-Beam Excitation	C. E. Hurwitz	Appl. Phys. Letters <u>8</u> , 243 (1966)
2794	High-Temperature Expansions — The Classical Heisenberg Model	H. E. Stanley T. A. Kaplan	Phys. Rev. Letters <u>16</u> , 981 (1966)
2802	Observation of the Interaction of Plasmons with Longitudinal Optical Phonons in GaAs	A. Mooradian G. B. Wright	Phys. Rev. Letters <u>16</u> , 999 (1966)
2806	Laser Properties of a Vapor-Grown Ruby	J. R. O'Connor P. S. Schaffer [†] R. A. Bradbury [†]	Appl. Phys. Letters <u>8</u> , 336 (1966)
2816	Band Structure and Laser Action in Pb _x Sn _{1-x} Tc	J. O. Dimmock I. Melngailis A. J. Strauss	Phys. Rev. Letters <u>16</u> , 1193 (1966)

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2822	Electroreflectance in Metals	J. Feinleib	Phys. Rev. Letters <u>16</u> , 1200 (1966)
MS-1294	Energy Band Parameter Determination in Graphite	M. S. Dresselhaus J. G. Mavroides	Carbon <u>3</u> , 465 (1966)

* * * *

UNPUBLISHED REPORTS

Journal Articles

JA No.

2723	Single Crystal Growth and Electrical Transport Properties of Intermediates in the Spinel System $\text{Co}_{1+\delta}\text{V}_{2-\delta}\text{O}_4$	D. B. Rogers A. Ferretti W. Kunmann	Accepted by J. Phys. Chem. Solids
2725A	On the Thermodynamic Aspects of the Temperature-Pressure Phase Diagram of InTe	M. D. Banus P. M. Robinson*	Accepted by J. Appl. Phys.
2768	Anomaly in the X-Ray Scattering of ZnSe	P. M. Raccah R. J. Arnott A. Wold*	Accepted by Phys. Rev.
2774	Generalization of the RKKY Interaction for Nonspherical Fermi Surfaces	L. M. Roth* H. J. Zeiger T. A. Kaplan	Accepted by Phys. Rev.
2824	Incoherent Source Optical Pumping of Visible and Infrared Semiconductor Lasers	R. J. Phelan, Jr.	Accepted by Proc. IEEE
2827	Efficient Ultraviolet Laser Emission in Electron Beam Excited ZnS	C. E. Hurwitz	Accepted by Appl. Phys. Letters
2832	First Order Raman Effect in III-V Compounds	A. Mooradian G. B. Wright	Accepted by Solid State Commun.
2852	High Pressure Synthesis of Arsenopyrite-Type Ternary Compounds	M. D. Banus M. C. Lavine	Accepted by Materials Res. Bull.
MS-1577	Single Crystal Growth and Electrical Transport Properties of the Spinel MgV_2O_4	A. Ferretti D. B. Rogers	Accepted by J. Phys. Chem. Solids

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Meeting Speeches*

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1520A	Self-Focusing of Optical Beams	P. L. Kelley	Bell Telephone Laboratories, Murray Hill, New Jersey, 14 July 1966
1571	Atomic Point Defects in Semiconductors	R. F. Brebrick	AIME, New England Regional Conference, Boston, 12-13 May 1966
1577	Single Crystal Growth and Electrical Transport Properties of the Spinel MgV_2O_4	A. Ferretti D.B. Rogers	International Conference on Crystal Growth, Boston, 20-24 June 1966
1578 A-D	Magnetoplasma Cyclotron Resonance in PbSe	S. Bermon	Michigan State University, 5 May 1966; Case Institute of Technology, 16 May 1966; Carnegie Institute, 17 May 1966; University of Maryland, 19 May 1966
1614	Spark Source Mass Spectroscopy	E.B. Owens	Fifth National Meeting, Society for Applied Spectroscopy, Chicago, Illinois, 13-17 June 1966
1627	Semiconductor Lasers	R.H. Rediker	IEEE Communications Conference, Philadelphia, Pennsylvania, 15-17 June 1966
1641	Intensity Fluctuations of Gas Lasers Below and Above the Threshold of Oscillations	C. Freed H.A. Haus†	Conference on Coherence and Quantum Optics, Rochester, New York, 22-25 June 1966
1675	Bulk GaAs Negative Conductance Amplifiers	A.G. Foyt A.L. McWhorter T.M. Quist	Solid-State Device Research Conference, Northwestern University, 15-17 June 1966
1677	Small-Bandgap Semiconductor Infrared Lasers	I. Melngailis A.J. Strauss J.O. Dimmock	
1693	Amplification at Subcritical Drift Velocities	A. L. McWhorter H. A. Haus†	
1706	Efficient Ultraviolet Laser in Electron Beam Excited ZnS	C.E. Hurwitz	
1676	Recent Work Concerning the Electrical Properties of Metal Oxides	J. M. Honig	National Bureau of Standards, Washington, D.C., 10 May 1966

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1679	Polaron Induced Anomalies in InSb	E. J. Johnson	Rensselaer Polytechnic Institute, 19 May 1966
1707	Crystal Growth from the Vapor	S. Fischler	E. I. du Pont de Nemours & Co., Wilmington, Delaware, 17 June 1966
1712	Introduction to IV-VI Compounds	A. J. Strauss	Semiconductor Materials Meeting, New York, 24 June 1966
1721	Introduction to Nonlinear Optics and Self-Focusing of Light Beams	P. L. Kelley	Tutorial Lectures, Advances in Quantum Electronics Symposium, University of Colorado, 20 June – 1 July 1966
1722	Laser-Induced Gas Breakdown	M. M. Litvak	

SOLID STATE DIVISION 8

I. SOLID STATE DEVICE RESEARCH

Laser emission has been observed in the wavelength region between 11 and 16 μ in several $Pb_xSn_{1-x}Te$ alloys at 12°K optically excited by radiation from a GaAs diode laser. Coherent emission was obtained from a $Pb_{0.86}Sn_{0.14}Te$ alloy sample at 11.6 μ , from a $Pb_{0.83}Sn_{0.17}Te$ sample at 14.9 μ and from a $Pb_{0.81}Sn_{0.19}Te$ sample at 15.9 μ . A model of the band structure of the $Pb_xSn_{1-x}Te$ alloy system has been proposed to explain the composition dependence of the band gap and the change in sign of the temperature coefficient of the band gap between PbTe and SnTe. According to our proposed band model, with increasing Sn composition the energy gap of $Pb_xSn_{1-x}Te$ initially decreases, goes to zero at some intermediate composition where the valence and conduction band edges become degenerate, and then increases, with the previous valence band now forming the conduction band edge and previous conduction band forming the valence band edge.

Laser emission has also been observed in the ultraviolet at several wavelengths between 3245 and 3300 \AA at both liquid helium and nitrogen temperatures from ZnS single crystals pumped by an electron beam. Up to 1.7 W of peak output power have been obtained with a power efficiency of 6.5 percent. As many as ten different laser lines have been observed emanating from a single sample at irregularly spaced wavelength intervals in this region. It was determined that these laser lines were emitted from different points on the cavity face. Each line presumably corresponds to a different laser filament, and the spatial variation in wavelength is most probably caused by crystal inhomogeneities. With high spectral resolution each of the different laser lines exhibits the familiar Fabry-Perot cavity mode structure. Because of the very large dispersion of the refractive index of ZnS near the energy gap, the mode spacing decreases rapidly with decreasing wavelength, from a value of 0.3 \AA at 3291 \AA to 0.16 \AA at 3245 \AA .

Using an electron beam we have also obtained laser emission from ZnO with a peak output power of 1 W and an efficiency of 1.3 percent at 4.2°K, and a peak output power of 0.5 W and an efficiency of 0.5 percent at 77°K.

CdS electron beam pumped lasers have had consistently higher threshold currents and lower power efficiencies than CdSe and CdS_xSe_{1-x} with x as large as 0.9. Using some new CdS platelets, we have now obtained CdS electron beam pumped lasers with thresholds and efficiencies more nearly in line with those of the other II - VI semiconductor lasers.

Xenon flashlamp pumping of semiconductor lasers was extended to shorter wavelengths and higher temperatures. Laser emission has been observed from InSb at liquid helium temperature and from CdSe, $CdS_{0.6}Se_{0.4}$, and CdS at both liquid helium and liquid nitrogen temperatures. The thresholds are comparable with those obtained in electron beam pumping and in InSb with diodes of this material.

The emission spectra at several injection levels has been obtained from diode lasers of PbS, PbTe, and PbSe. The emission spectra for the three materials are similar and remain

unchanged with increasing injection level. The invariance of spectral shapes and peak positions with increasing diode current suggests an absence of band filling, and that injected carriers may be nondegenerate, even at laser threshold.

II. OPTICAL TECHNIQUES AND DEVICES

The electro-optic effect has been observed in crystalline selenium (32 point-group symmetry) for $10.6\text{ }\mu\text{m}$ radiation; the value of the coefficient r_{11} was measured to be $\sim 2.5 \times 10^{-10}\text{ cm/V}$. Trigonal selenium, which is uniaxial and piezoelectric, appears to be the first elemental crystal in which the electro-optic effect has been observed. The value given above is in agreement with a phenomenological theory of optical harmonic generation, optical rectification, and the linear electro-optic effect set forth by R. C. Miller in 1964.

III. MATERIALS RESEARCH

Metal solution calorimetry has been used to determine the heat of formation for InSb(111), the new high-pressure phase reported recently, as well as the heats of formation for atmospheric-pressure InSb(I) and high-pressure InSb(11). The results of x-ray diffraction and superconducting transition temperature measurements show that InSb(111) is not the same as the orthorhombic high-pressure phase of InSb.

The resistivity of MnAs at 77°K has been measured as a function of hydrostatic pressure. The data show that at this temperature the B8 structure stable at atmospheric pressure is transformed into the B31 structure at 4.5 kbar. This result confirms the conclusion that above 4.5 kbar the B31 structure is stable down to the lowest temperatures.

Negative magnetoresistance has been observed at 4.2° and 77°K in single crystals of Ti_2O_3 doped with 1 to 3 atomic-percent V. At 4.2°K , the resistivity is reduced by about 10 percent at 170 kgauss, the highest magnetic field employed. The negative magnetoresistance is attributed to the presence of V with localized magnetic moments.

On the basis of x-ray diffraction and electrical conductivity data for LaCoO_3 , the first-order phase change which occurs in this compound at 937°C has been identified as a localized-electron \Rightarrow collective-electron transition. The x-ray results show that the crystal space group is $R\bar{3}c$ below 375°C and $R\bar{3}$ above this temperature. Ordering of high-spin and low-spin Co ions occurs on the two types of octahedral Co sites distinguishable in the $R\bar{3}$ symmetry.

X-ray diffraction studies have shown that PbRuO_3 has a modified pyrochlore structure containing ordered oxygen vacancies, which act as electron traps. The structure is stabilized by trap-mediated cation-cation bonds between the four lead ions neighboring each oxygen vacancy.

Laser action has been observed in $\text{YVO}_4:\text{Nd}$ rods at pulsed thresholds of 2-3J, which are comparable to those obtained for YAG:Nd lasers. The strong yellow fluorescence excited by 2537 or 3660 \AA radiation in pure YVO_4 is completely quenched in $\text{YVO}_4:\text{Nd}$ crystals. The quenching is attributed to energy transfer from the host lattice to the Nd^{+3} ions.

An analytical method based on automatic potentiometric EDTA titrations has been developed for the determination of Pb and Sn in PbTe-SnTe alloys. Accuracies of 1 to 2 parts per 1000 have been obtained for titrant volumes in the 2 to 10 ml range.

IV. PHYSICS OF SOLIDS

Sensitive modulation techniques are being used to study the reflectivity and the magneto-reflectivity of solids in the vacuum ultraviolet, visible, and near infrared regions of the spectrum. In addition to the magneto-piezo-optical technique which was reported in the last Solid State Research Report,* studies have been initiated using electroreflectance, by means of an electrolyte, magneto-electroreflectance, and also modulation by passing pulsed electric currents through a sample. Our experimental results suggest that the latter effect is due to thermal modulation. Preliminary room temperature results in germanium, InSb, and GaSb have demonstrated an impressive enhancement of the resonances associated with interband transitions across energy gaps. Furthermore it has been demonstrated the electroreflectance technique even works as well in metals as in semiconductors.

Far infrared studies of the Zeeman effect in germanium doped with the Group III impurity gallium have now been extended to high magnetic fields. Additional splittings of the lines have been observed.

The study of propagation of 9 GHz longitudinal ultrasonic waves in n-InSb at low temperatures and magnetic fields up to 25 kG has been carried out. This experiment has yielded a direct determination of the magnitude of the piezoelectric constant e_{14} and the conduction band deformation potential C_1 .

Recently observed nonlinearities in the interband magneto-absorption in InSb have been interpreted in terms of electron-LO phonon interaction on the conduction band Landau levels. However, the high field magneto-absorption states may be almost entirely bound exciton-like; the effect of electron-phonon interaction on the energy of the bound exciton states in strong magnetic fields is now being investigated.

Using the Slater-Koster technique, secular determinants have been set up for TiO_2 , TiO, TiN and TiC. Transfer integrals have been evaluated for the last three materials.

Previous investigators have usually reported a local maximum in the susceptibility of LaCoO_3 at 90°K, except for one recent single crystal study. Our study indicates that the magnetic properties of this chemically pure material are strongly dependent on the method of preparation. Samples have been obtained which exhibit the susceptibility maximum, and this maximum can be removed by additional regrinding and refiring.

X-band magnetic resonance linewidth studies of polycrystalline ferromagnetic chalcogenides are continuing. The temperature dependence of the resonance linewidth has been measured for CdCr_2Se_4 and CdCr_2S_4 .

Antiferromagnetic resonance has been observed at millimeter wavelengths in the normal cubic spinels ZnCr_2Se_4 and ZnCr_2S_4 . In ZnCr_2Se_4 , a discontinuity was observed in the resonance field at the Néel temperature suggesting a first order transition. No such discontinuity was found in ZnCr_2S_4 , and the temperature dependence of the resonance suggests a second order transition.

Calculations by means of high temperature expansion techniques of properties of a classical Heisenberg magnet are continuing. Contrary to proposals by others, it is found that the

*Solid State Research Report, Lincoln Laboratory, M.I.T. (15 May 1966).

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form of the divergence of the zero-field static susceptibility does depend on the spin quantum number S . Furthermore, evidence is presented that a phase transition exists just as convincingly in the two-dimensional Heisenberg model with nearest neighbor ferromagnetic interactions, as in the three-dimensional case.

A proof has been given of the virial theorem for a homogeneous interacting electron gas in a uniform background of positive charge.

A perturbation-type calculation shows that for a large class of orbitals the ground Slater determinant of minimum energy for the H^- ion is not a bound state.

A theoretical analysis of the possible improvement in the efficiency of energy conversion by using inhomogeneously-alloyed materials is being carried out.

Stimulated Brillouin scattering in single crystal quartz has been studied in the temperature range 2.1 to 300°K. Contrary to recently reported Russian work, no increase in the Stokes shift is found at temperatures below 80°K.

The study of the temperature dependence of second harmonic incoherent scattering is continuing. A calculation which includes internal optical and static fields but neglects orientation correlation explains qualitatively, via the fourth rank susceptibility tensor, the rapid decrease of scattering observed in CCl_4 when approaching the boiling point.

Raman scattering from charge carrier plasmons has been observed for the first time in a solid. The results have verified the recently predicted theoretical behavior of a plasmon-phonon system.

First order infrared Raman spectra have been observed for the first time in solids; the materials studied have been GaAs, InP, AlSb and GaP. Up to now, Raman scattering had not been observed in the first three of these semiconductors.

The Raman cross section for light scattering by electrons making transitions between Landau levels in the conduction band of a semiconductor has been calculated, and appears for InSb to be two orders of magnitude greater than previously published estimates which neglected the effects of degenerate valence bands.

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